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ON THE VARIATION IN THE STRENGTH OF A MUSCLE.

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With a Plate.

THE strength of a muscle is the maximum weight which it is capable of lifting at a single impulse. It is practically impossible to measure this strength directly, as it necessitates several trials, during which the muscle becomes fatigued. It may, however, be determined indirectly by a method which I shall make the subject of a future paper.

The evidence which we shall now present of variation in muscular strength from day to day, is seen in the variation in the amount of work done by the muscle, before exhaustion. We present here three series of experiments upon the right arms of myself and a former pupil, Mr. D. A. Myers. The first series consisted in finding the maximum pull, which the muscles could exert upon the spring of a dynamometer. The arm was stretched horizontally, grasping the hook of the dynamometer, the palm of the hand being downward, the pull was

exerted upward. The arm moves in the vertical plane which makes an angle of 45° with the transverse plane.*

In this case, part of the work of the muscles consists in moving the hook of the dynamometer over a certain space. x, under a constantly increasing strain P. The rest of the work done consists in sustaining the strain P, and the fatigue caused is due wholly to molecular motions in the muscle itself. Prof. Haughton has proposed to call the former work "dynamical," the latter "statical" work.

The dynamical work D is then

$$D=\int P.dx, \text{ or as } P=c\,.\,x$$

(where c is the tension of the dynamometer spring when $x=$ unity.)

$$D=\int cxdx=\frac{cx^2}{2}+c''$$

or between the limits $x=0$ and $x=\frac{P}{c}$

$$D=\frac{P^2}{2c}. \qquad (1)$$

In like manner the statical work S is

$$S=\int Pdt \quad \text{or as} \quad P=c't$$

where c' is the value of P when t is unity—

$$S=\int c'tdt=\frac{c't^2}{2}+c'''.$$

or between the limits $t=0$ and $t=\frac{P}{c^1}$

$$S=\frac{P^2}{2c'} \qquad (2)$$

* Prof. Haughton has criticised this position (Nature, vol. xi, p. 488), his point being that some muscles are called into play irregularly. He suggests that the arm should move in the transverse plane, with the palm of the hand upward. This position is a very unnatural one, and the arm will be wholly fatigued in two or three minutes by simply holding the arm in this position when its weight is supported by an external force. Although Prof. Haughton's opinion on this subject is worthy of grave consideration, yet I am not prepared to adopt it in this case. The manner of experiment is determined to some extent by the end to be accomplished, and I am still of the opinion that I have reduced the errors of experiment to a minimum. This point, however, deserves further attention.

The value of D is measured in kilogram-meters; the value of S is measured in kilogram-seconds. It will be admitted that the statical work of holding a weight of w. kilos upon the out-stretched arm, is equivalent to the dynamical work of lifting w. kilos through a certain space. Calling the total work W, we shall have—

$$W = D + k \, . \, S. \tag{3}$$

I propose to call k the dynamical equivalent of statical work. No value has yet been obtained for it which can be deemed more than approximate.

In a series of experiments still in my possession, in which the object was to find the relation of the strength (s) to the dynamical work of exhaustion, P was taken provisionally as a measure of the strength. Its variation from day to day is shown graphically on the chart. My experiments are represented by curve F, F; those of Mr. Myers by curve E, E. The strength is laid off on the ordinates. Time is in days laid off on the axis of abscissa. The values of (s) determined on the same day are represented by the small circles which lie in the same vertical.

The second series consisted in finding the dynamical work done before exhaustion, in lifting a weight of 5·0 kgr. through a height of 0·7 meters in 1·25 seconds. The manner of experiment has already been described in former papers.* The results of these experiments are shown on the chart. The broken line A B is the series of constant experiments given in the first table, on page 133 of this Journal, for Feb., 1875. The dates of the individual experiments are not known, but no two experiments were separated from each other by an interval of more than two days. Soon after this series was finished, the series represented by the line B C was begun, and these experiments are accurately represented in time. The ordinates represent the number (n) of times the weight was lifted before exhaustion, and are laid off on the scale to the left of the chart. D D represents the experiments of Mr. Myers with the same weight, laid off on the scale to the right of the chart.

* This Journal, Feb., 1875, pp. 130–137. Nature, vol. xi, p. 276.

The third series was made with a view of finding the relation of strength to statical work of exhaustion. The statical work consisted in holding a weight of 5·0 kgr. upon the horizontal arm, the position of the arm being the same as before. The time (t) of exhaustion from day to day (in seconds) is shown in the broken lines G, G and K, K the former being my own experiments, the latter those of Mr. Myers.

During the time of these experiments the muscles were kept in gentle training by daily exercises on the swinging rings and parallel bars. This exercise was taken every day, whether experiments were made or not,* and was found very beneficial in reducing the daily variations in strength. On stopping the experiment for a few days the decrease in the power of the muscle is very apparent, and the influence appears most marked upon the observations of the dynamometer. This is due to a difference in training, and it is one of the most difficult points in the whole subject. Two different muscles may have equal strength when measured with the dynamometer, and yet one may be capable of doing twice as much dynamical work as the other with a moderately light weight. This makes it necessary that such experiments should be made on trained muscles.

It will be seen that Mr. Myers is considerably stronger than I, and that variations in the amount of work done are greater for him than for me. This means that variations in strength cause greater variations in the work done by him than in my own case. This is entirely in harmony with the equation given at the close of my paper in this Journal, February, 1875.

During the whole of this series of experiments the size of the muscles did not perceptibly change, while in Myers' experiments the number of lifts with a 5 kgr. weight varied, in two successive experiments (Dec. 20 and 23) from 420 to 1,300.

On the 29th of April, 1873, after a month of exceedingly severe mental work, I was present at a terrible accident, occasioned by the burning of a building. For a quarter of an hour I was under severe mental strain and was for a week completely prostrated. The urinary deposits were enormous, and the condition of the nerves may be inferred from a specimen signature

* The time of the summer vacation excepted.

executed, May 6th, after having run violently up a short flight of stairs. Out of about 30 signatures made at that time this was the best. My ordinary penmanship is shown in the signature below, executed on recovery. While in this condition a few experiments were made with the dynamometer, and in lifting the 5·00 kgr. weight, they lie between the dates, April 29 and May 8, inclusive, and are limited by the points marked *a–b* on diagrams F, F and B, C. It will be observed that here, also, the observations with the dynamometer are most affected, while the dynamical work is not perceptibly affected.

Two important results follow from this investigation:

1. After the relation of the strength of a muscle to the dynamical work of exhaustion has been determined, the strength at any time will be most accurately determined, by measuring the dynamical work of exhaustion. On days when from any cause the muscles are temporarily weak, the strength as determined by the dynamometer, and the work of exhaustion with very heavy weights, is less. In exhaustion with lighter weights, however, (5· kgr.) the exercise of the first part of the experiment appears to invigorate the muscle, and the influence of temporary weakness, due to errors in diet, or lack of exercise, or the oppressive atmosphere of the room, is eliminated.

2. The coefficient of muscular power per square centimeter of section of the muscle, is a quantity which varies greatly with different muscles, and with the same muscle at different times; or in other words, the work which a muscle can perform, depends not only upon its size, but also upon its quality.

This helps to explain the different results arrived at in the determination of the coefficient of contraction of different muscles. Thus, the following values in kgrs. per sq. cm. have been found by various experimenters.*

1. Flexors of arm, --------	8·99	(Henke.)
2. " " " --------	8·19	"
3. " " " --------	6·67	(Haughton.)
4. Extensors of foot, -----	5·90	(Henke.)
5. " " " -----	11·60	(Koster.)
6. Flexors of leg, --------	7·78	(Haughton.)

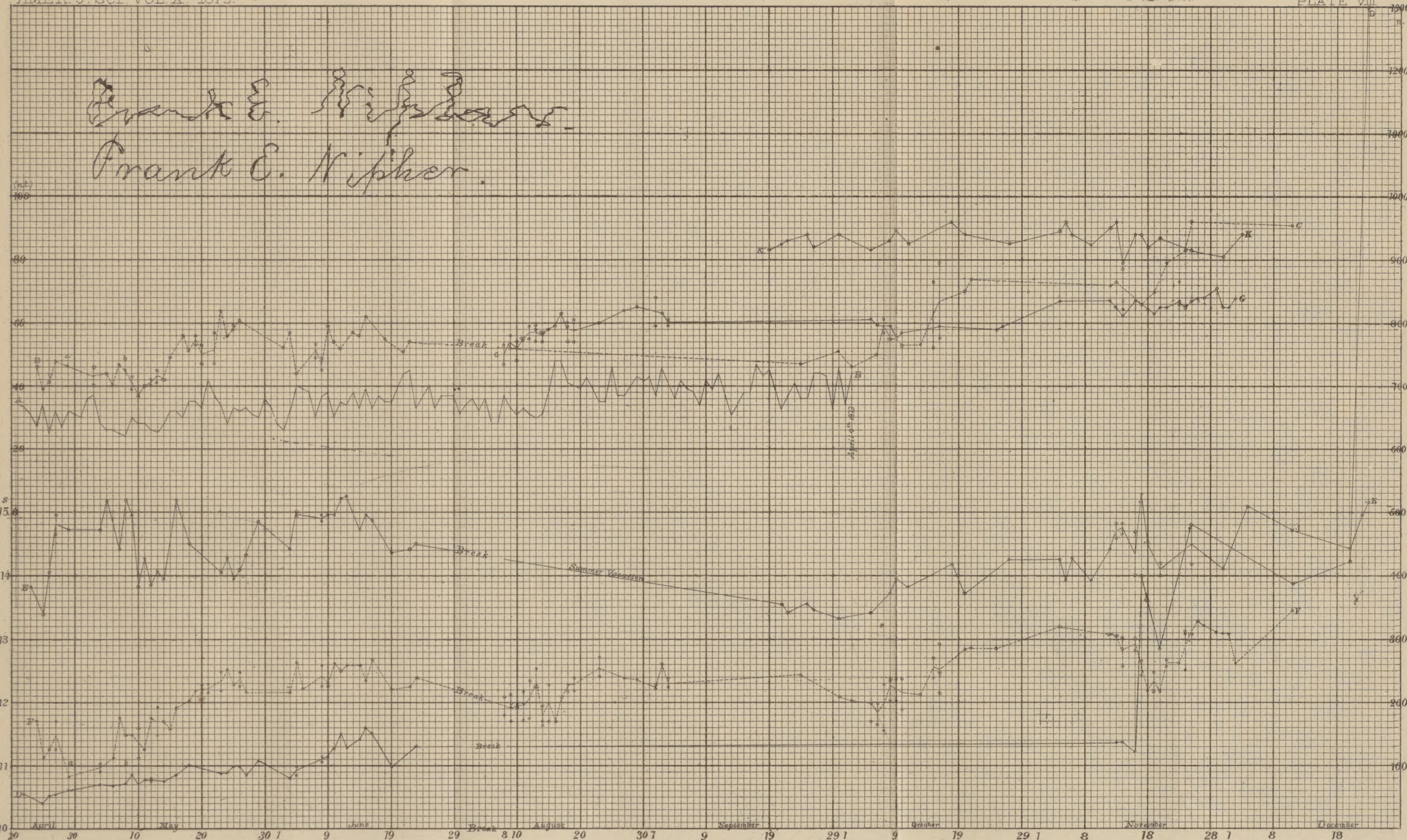
* Haughton's "Animal Mechanics." London, 1873, p. 70.

Haughton has pointed out other reasons for such differences, but one of the most important reasons is found in the amount of training which the muscle has received. Hence, muscles which are seldom called into action, have not the same contracting power as those which are daily used.

The experiments here described, as well as those before given in this Journal, were performed while I was an assistant in the laboratory of Prof. Gustavus Hinrichs, to whose kindness I am under many obligations. I also take pleasure in acknowledging experimental aid from Prof. W. C. Preston and Mr. D. A. Myers.

St. Louis, June 15th, 1875.

PLATE VIII



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